

**BUREAU OF SUGAR EXPERIMENT STATIONS  
QUEENSLAND, AUSTRALIA**

**FINAL REPORT – SRDC PROJECT BSS245  
ENHANCING RESISTANCE TO  
YELLOW SPOT DISEASE**

**by  
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## TABLE OF CONTENTS

	Page No.
<b>SUMMARY</b>	
<b>1.0 BACKGROUND</b> .....	1
<b>1.1 The disease</b> .....	1
<b>1.2 Unknowns</b> .....	1
<b>2.0 OBJECTIVES</b> .....	2
<b>3.0 METHODOLOGY</b> .....	2
<b>3.1 Resistance screening</b> .....	2
<b>3.1.1 Disease estimation</b> .....	3
<b>3.1.2 Canes screened for resistance</b> .....	3
<b>3.2 Yield loss studies</b> .....	3
<b>3.2.1 Fungicide trials</b> .....	4
<b>3.2.1.1 Small plots</b> .....	4
<b>3.2.1.2 Large plots</b> .....	4
<b>3.2.2 Breeding trials</b> .....	4
<b>3.3 Influence of environment</b> .....	5
<b>3.3.1 Laboratory studies</b> .....	6
<b>3.3.2 Weather-monitoring equipment and data</b> .....	6
<b>4.0 RESULTS</b> .....	6
<b>4.1 Resistance screening</b> .....	6
<b>4.2 Yield loss studies</b> .....	8
<b>4.2.1 Fungicide trials</b> .....	8
<b>4.2.2 Breeding trials</b> .....	10
<b>4.3 Influence of environment</b> .....	15
<b>4.3.1 Laboratory studies</b> .....	15
<b>4.3.2 Weather data analyses</b> .....	16
<b>5.0 DISCUSSION</b> .....	17
<b>6.0 OUTPUTS</b> .....	19
<b>7.0 EXPECTED OUTCOMES</b> .....	20
<b>8.0 FUTURE RESEARCH NEEDS</b> .....	20
<b>9.0 RECOMMENDATIONS</b> .....	20
<b>10.0 PUBLICATIONS ARISING FROM THE PROJECT</b> .....	21
<b>11.0 ACKNOWLEDGMENTS</b> .....	21
<b>12.0 REFERENCES</b> .....	21

## APPENDICES

## SUMMARY

Yellow spot is a leaf disease caused by the fungus *Mycovellosiella koepkei*. Although known in Queensland since 1950, some facets of the disease have never been adequately researched. Yellow spot principally, but not exclusively, affects cane in the wet tropical coastal areas of Queensland. The disease is favoured by warm wet conditions, usually being observed during and shortly after the wet season (March-May). Up to 50,000 ha may be affected in Queensland in years of above average rainfall. Little yield-loss research had previously been conducted and there was a need to review the current breeding strategy to ensure adequate resistance in commercial varieties.

Research associated with this project aimed to:

1. determine yield losses resulting from the disease;
2. assess the current levels of resistance in the Australian germplasm;
3. make recommendations regarding the current breeding strategy.

Research outputs impinged on each of these areas. Resistance was assessed on the basis of leaf areas diseased at the peak of the disease epidemic (April-May). Assessment of parent canes and commercial cultivars suggested there is less resistance to yellow spot than to the other important diseases in northern Queensland, including *Pachymetra* root rot and orange rust. This is a cause for concern and warrants consideration by breeders and pathologists. There were only minor differences in the proportion of resistant, intermediate and susceptible parents sourced from each district (Northern, Herbert, Burdekin, Central and Southern).

Yield-loss research with fungicides showed that yellow spot may reduce the CCS of susceptible clones by up to 2 units early in the harvest season. In resistant clones, as expected, losses were negligible. Selection trials in the breeding program (FATs) were also utilised to assess yield losses and the influence of clonal resistance on losses. This approach again showed that yellow spot may reduce yields significantly, especially in the wetter years. In the 2001 season, yellow spot was of greater significance than either orange rust or *Pachymetra* root rot. Losses of up to 20% in cane and sugar yields were observed.

An analysis of the conditions required for spore germination showed that high relative humidity (>99%) and relatively high temperatures (20-30°C) were needed for spores of *M. koepkei* to germinate. This correlates with disease incidence, since it is most severe on the wet tropical coast. An analysis of Bureau of Meteorology data for Cairns, Townsville, Mackay and Brisbane indicated that Cairns was the most favourable site out of these three; again consistent with disease observations. Further studies on environmental conditions favouring the disease, and the analysis of longer-term weather data may facilitate an assessment of the probability of severe disease outbreaks in cane-growing areas. By linking this with yield loss research, it may be possible to accurately identify the level of resistance needed in commercial canes to minimise commercial losses.

## 1.0 BACKGROUND

Yellow spot is a leaf disease that was first recognised in the Queensland industry in 1950. Since then, the disease has been regularly observed on the wet tropical coast, where it affects the leaf health of commercial crops. Very little yield-loss information has been generated in Australia, resulting in a low level of awareness of the effects of the disease (Magarey and Croft 1998). Egan (1973) undertook preliminary yield-loss studies and found that the disease could reduce sugar content (CCS) significantly, by up to 2 units early in the harvest season. Research in Mauritius suggests the disease can substantially reduce both cane and sugar yield, with large and significant effects on CCS (Ricaud *et al.* 1980).

With this background, research into yellow spot associated yield losses and the development of appropriate strategies for the plant improvement program were further investigated in Queensland.

### 1.1 The disease

Yellow spot is caused by the fungal pathogen *Mycovellosiella koepkei* (Krüger) Deighton (Autrey and Saumtally 2000). Wind-blown spores spread the pathogen and high rainfall favours the disease. As a result, the disease peaks during the wet season and disappears with the dry, cool winter conditions. Yellow spot occurs regularly between Tully and Cairns and in the wetter parts of the Herbert and Mossman mill areas. In years with above average rainfall, the disease may also occur in the Burdekin and Mackay districts. In these years, up to 50,000 ha may be affected in Queensland. Little is known of the environmental requirements for the disease beyond the need for high rainfall and warm temperatures.

In the wetter decade of the 1970s, yield losses from yellow spot were highlighted and some attention was paid to the disease in the breeding program. Resistance screening generally consisted of *ad hoc* observations in variety trials and commercial field plots. Since then, little data have been generated regarding the resistance of commercial canes or of parents in the breeding program. This has resulted in the commercial cultivation of a number of susceptible cultivars, such as Q117 and Q124, canes that have dominated some Queensland districts.

### 1.2 Unknowns

Unknown aspects requiring research and that would improve management and reduce the economic impact of the disease include:

- yield losses caused by the disease in Queensland;
- the relationship between resistance and yield;
- the resistance of current commercial clones;
- changes required in the breeding program to improve resistance levels.

## 2.0 OBJECTIVES

The specific objectives of the project were to:

- quantify CCS and yield losses caused by yellow spot in commercial cultivars;
- assess the efficiency of selection for yellow spot resistance operating in the plant improvement program;
- initiate strategies for improving CCS in the plant improvement program, particularly relating to reduced levels of yellow spot in commercial crops.

Within these objectives, research was directed in three areas.

**Resistance screening.** Methods were developed and/or adapted for screening for leaf disease resistance. Trials from the later stage of the plant-improvement program were accessed and the resistance of these clones quantified. The screening of parents for the disease had never been regularly undertaken before and the best and/or most commonly used parents at the Meringa Sugar Experiment Station were screened.

**Yield loss studies.** Initial research employed fungicides in small plots to assess the effect of the disease on yield. Difficulties with this approach facilitated the use of alternative methods and accordingly, a statistical analysis of later-stage breeding trials was undertaken. This also provided a good understanding of the relationship between resistance and yield.

**Influence of environment.** More precise information was obtained on the conditions required for disease development. This information allows the better prediction of severe yellow spot occurrence, an indication of the likely variation in disease levels year by year, and an estimate of the associated yield losses. In turn, recommendations can then be made to plant breeders regarding the level of resistance needed in commercial clones.

The project commenced in July 1999 and ended in December 2002. Funding allowed for the employment of casual labour for the operation of field trials and data analysis.

Data gathered during this study have resulted in several publications (some under review); copies of these publications detailing all results are included in the Appendices. A summary of the methodology, results and discussion is given below.

## 3.0 METHODOLOGY

### 3.1 Resistance screening

Most screening for disease resistance within the Queensland sugar industry occurs at BSES Experiment Stations. Prior to this project, there was very little specific screening for leaf diseases within BSES. Observation of the amount of disease in clones in the breeding program was made, but generally this was done on a subjective basis. For many years, there had been no screening of parent canes for resistance to yellow spot.

### 3.1.1 Disease estimation

To assess the resistance of clones, a quantitative assessment of the amount of disease in clones was needed. A leaf-disease computer-simulation program, developed by Dr Forrest Nutter (Iowa State University, USA) and based on the estimation of percent leaf area diseased, had been obtained previously. This software enables researchers to hone their skills in estimating diseased leaf areas, facilitating accurate quantitative field assessment of disease incidence.

In individual field plots, we selected four leaves from four different stalks (from the same relative leaf position in the canopy) and assessed disease levels in the central section (half-way along the leaf) of each leaf. This ensured repeatable results and suitable comparison between clones. In assessing leaf area diseased in clones, a minimum of two assessors worked in tandem with independent estimation of leaf areas affected in any one clone. Estimates of the leaf areas diseased in each of the four leaf pieces were recorded for each assessor and a mean figure of all data for that clone used in resistance calculations.

### 3.1.2 Canes screened for resistance

The following trials and clones were screened for resistance in this project:

- Final Assessment Trial (FAT), South Johnstone (1999 series). This trial was screened in 2000 and contained over 80 promising clones.
- Parent clones. Two hundred of the most commonly used parents held at Meringa Sugar Experiment Station, and used in making crosses for most parts of the Queensland industry, were screened each year in 2000 and 2001. Low disease levels in 2002 meant there was insufficient disease to accurately determine resistance in that year. The average resistance ratings for parents from different parts of Queensland were analysed and graphed.

From these analyses, conclusions regarding the current level of resistance in the Australian germplasm were made. Resistance ratings also provided a basis for assessing the relationship between resistance and yield losses (see below).

We developed the new term Resistance Index (RI) to define resistance levels and defined it as ‘the average resistance rating calculated from all members of a breeding population (a set of clones or cultivars)’. It expresses a measure of the level of resistance within the population (but no measure of variability). The range of the index is between 1 (highly resistant) and 9 (highly susceptible). A high value indicates vulnerability of the whole population to disease, whilst a low value indicates the reverse. The RI of the South Johnstone FAT population was quantified and compared to the RI values for *Pachymetra* root rot and orange rust in the same clonal population.

## 3.2 Yield loss studies

Two strategies were used – the first involving the use of fungicides and the second relating clonal resistance in FATs to yield.

### 3.2.1 Fungicide trials

Initial research concentrated on the use of fungicides with a comparison of yields in sprayed and unsprayed plots. The fungicide benomyl (Benlate®) is known to be effective in controlling the disease (Ricaud *et al.* 1980) and had been used with good success in previous preliminary trials in Tully. Two fungicide trials were established, one using small plots (4 m by 3 m), the other with field plots four rows by 10 m long.

#### 3.2.1.1 Small plots

**Trial design.** Small plots (4 m by 3 m) were established with each of the 12 cultivars Q78, Q107, Q124, Q133, Q135, Q138, Q152, Q158, Q159, Q162, Q165<sup>A</sup>, Q167<sup>A</sup>, CP57-526 and H56-752 in a randomised complete-block design with two replicates. These cultivars are known to vary in resistance from highly resistant to highly susceptible. Plots were established with pre-germinated plants spaced on a square grid pattern, with 1-m gaps and 12 plants per plot. Gaps were left between plots so that a small tractor with a spray boom could travel between each plot; this ensured even fungicide coverage of crop canopies and enabled easy access for disease assessments. The trial was conducted on Tully Sugar Experiment Station in 2000-2001.

**Harvest parameters.** Problems were encountered with plant establishment and this meant that cane-yield data for some plots were questionable. We decided not to assess cane yield but to undertake the CCS analysis, since some reduction in plant numbers was not considered critical for CCS. Stalks were cut by hand and CCS analyses undertaken using a small mill and standard industry assessment procedures.

#### 3.2.1.2 Large plots

We used plots four rows by 10 m long with three replicates of each cultivar-spray treatment. The cultivars were Q96, Q107, Q117, Q124, Q127, Q138, Q152, Q158, Q162 and H56-752, representing a range in resistance to yellow spot. Fungicide sprayed and unsprayed plots were included; benomyl was applied at 2-4 week intervals depending on the weather conditions. The experiment was planted in mid-2001 and harvested on 23 September 2002. Sugar content (CCS) and cane yield were recorded at harvest.

### 3.2.2 Breeding trials

Later-stage trials in the plant improvement program offer a unique way to determine how clonal resistance influences disease-associated losses. The fungicide trials had statistical limitations because of the restricted number of clones able to be included in each experiment (logistics problem). Breeding trials include over 80 clones and analyses therefore have a greater degree of significance (more statistical degrees of freedom).

**Method.** The method relies on the assessment of the resistance of all clones in a breeding trial and relating the yield (CCS, tonnes cane/ha, or tonnes sugar/ha) of these clones to their disease resistance. It was assumed that any underlying yield effects of the disease would be expressed in the tendency for reduced yield in highly susceptible clones. There is no doubt other factors influence clonal yield, such as genetic yielding ability and the variable influences of agronomic factors and other diseases and pests on individual clones. To remove these effects (in order to examine the underlying influence of yellow spot), the average yield of all clones with the same resistance rating (1 to 9 basis) was regressed against yellow spot resistance. The significance of the regression between these

parameters was tested and conclusions drawn. If a regression was not significant ( $P>0.05$ ), the regression line was not drawn and only the individual points of the data are displayed in the figure.

The new term Yield Loss Resistance Index (YLRI<sub>5</sub>) was developed to assist in the analysis of yield by resistance relationships. This is a term to be used in association with resistance by yield loss regression analyses. It is calculated as the level of resistance (in breeding-trial yield-loss assessments), where losses are a given percentage below those in 1-rated (the most resistant) clones; a subscript on the abbreviated name denotes the percentage yield loss. It is calculated using the slope of the regression line. For example, YLRI<sub>5</sub> will mean that at that level of resistance, yields are 5% lower than those in 1-rated clones. A subscript of 10 will mean 10% lower, 15 will mean 15% lower, etc. As a further example, if the YLRI<sub>5</sub> was calculated as 4.5, this would mean any clone with a resistance rating of 4.5 would have yielded exactly 5% less (a 5% yield loss) compared to the most resistant (one rated) clones. If on the other hand, the YLRI<sub>5</sub> value was 9.0, this would imply even highly susceptible clones (with a resistance rating of nine) yielded only 5% lower than the most resistant clones. The YLRI index, therefore, provides an instant guide as to the level of resistance needed in clones to keep disease-associated yield losses at a certain level.

A FAT at South Johnstone was selected initially and all clones screened for disease resistance in late April 2000. Resistance ratings on a 1 (highly resistant) to 9 (highly susceptible) scale were applied to clones.

**Analyses.** Two analyses were undertaken.

*Early versus late-season CCS effects.* Research in Australia and Mauritius suggests that yellow spot significantly reduces CCS early in the harvest season, but that these effects disappear, as the disease disappears, mid season. Accordingly, we collected six-stalk samples of all clones in the FAT late May 2000 (early season) and again at the normal trial harvest time of mid-September; at the latter, effects of yellow spot on CCS were considered negligible. Changes in CCS in each clone between early and mid-season were then calculated. If yellow spot was influencing CCS in susceptible clones early in the season, this was expected to show up in variation in the differences in CCS in comparisons between resistant and susceptible clones.

*Yield effects (tonnes cane and tonnes sugar).* The relationships between cane yield, sugar yield and resistance were examined as described above using data from the mid-season harvest. Data from clones were averaged on a resistance-rating basis and the relationship between resistance and yield examined for both cane yield and sugar yield. Following these analyses, the resistance ratings of clones (common between FATs on the wet tropical coast) were used in a similar way with yield data from the four other FATs located in the region (Tully to Gordonvale). Plant crops only were analysed.

### 3.3 Influence of environment

To relate yield losses to climate and weather, and therefore to be able to predict the probability of yield losses from the disease using long-term weather data, studies were made into the environmental parameters affecting disease development. With limited resources available in this project, only spore germination was targeted. Weather Bureau data were then accessed from four cities (Cairns, Townsville, Mackay and Brisbane) to



test the model generated for predicting disease incidence. Further studies will be needed to investigate how the weather affects other aspects of disease development.

### 3.3.1 Laboratory studies

Conidia of *M. koepkei* were collected from a crop of a susceptible sugarcane cultivar at Tully (17.9°S, 146.6°E), northern Queensland. Pathogen identity was initially confirmed by symptomatology and later from the appearance of spores under a microscope. Conidia were used in experiments soon after collection from diseased leaf material. Spores were deposited on glass slides; spore deposition was such that spore densities were neither so great that germination could not be viewed, nor so sparse that sufficient spores could not be counted per slide. Two glass microscope slides covered in spores were placed within a small (11 by 7.5 by 5 cm) plastic sealable container (lid plus base). The base consisted of a perforated platform with a watertight space below. The lid was placed on the base and the container sealed. Germination was assessed after 24 hours by counting germinated and non-germinated spores (total of at least 100 spores per slide) under 20x magnification.

Spore germination at different relative humidity was examined using humidities created using solutions of KOH of different concentrations (Solomon 1951); individual solutions were placed in the base of the plastic containers.

We used a multirange incubator, with chambers maintained at different temperatures, to assess the temperature requirements for germination of *M. koepkei*. Maximum and minimum temperatures varied slightly between each experiment but chamber temperatures were close to 7, 12, 16, 19, 21, 23, 26, 28, 30 and 34°C.

### 3.3.2 Weather-monitoring equipment and data

Historical weather data (1996-2001) were obtained from the Bureau of Meteorology for Cairns, Townsville, Mackay and Brisbane. These data included half-hourly records for relative humidity, temperature and rainfall.

Following spore germination research, optimum requirements for spore germination were generated and weather data analysed. This provided a guide as to the hours each year where conditions were suitable for germination. Hours of suitable conditions were totalled and the favourability of each area (Cairns, Townsville, Mackay and Brisbane) for spore germination was quantified.

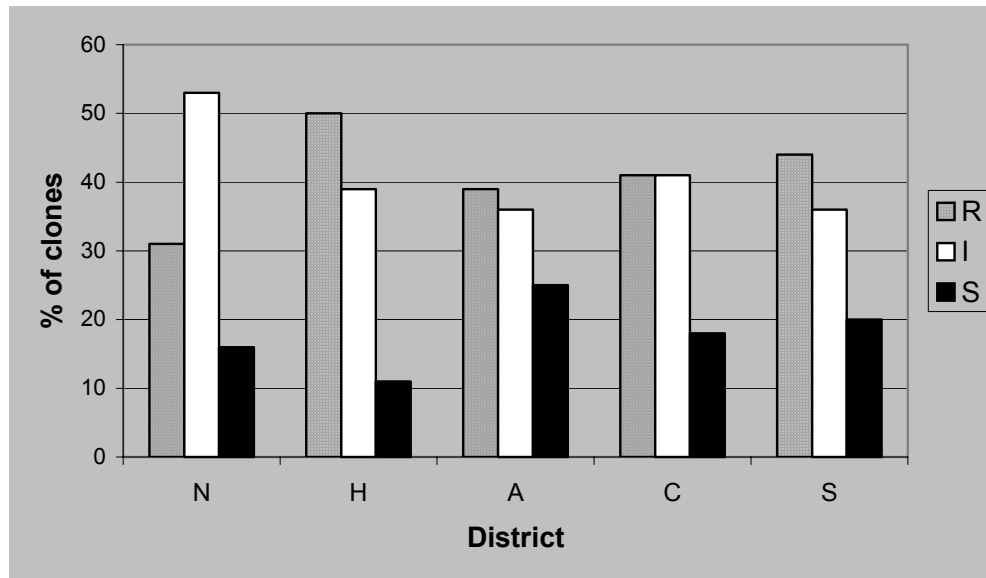
## 4.0 RESULTS

### 4.1 Resistance screening

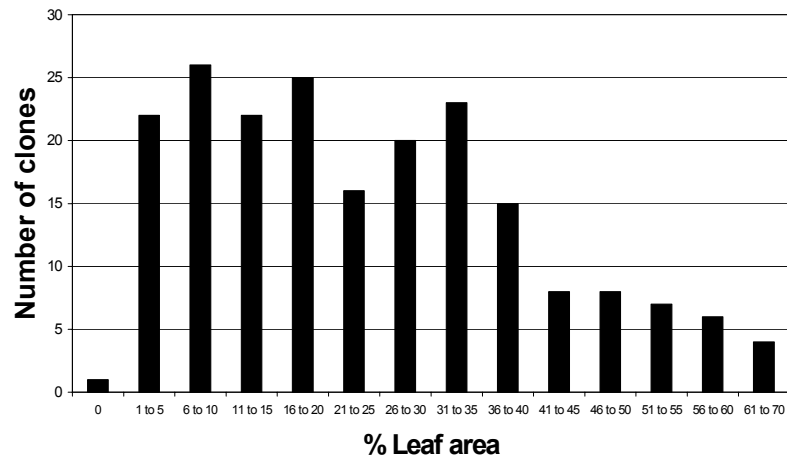
Our screening showed that there was considerable variation in the resistance of clones in both the later stages of the breeding program and also in parent canes in each district of the Queensland program (Figures 1 and 3).

Table 1 compares the Resistance Index (RI) and the Yield Loss Resistance Indices (YLRI<sub>5</sub>) of clones in the South Johnstone FAT to those for *Pachymetra* root rot and orange rust in the same trial (results for these diseases were taken from other disease assessments and analyses). This indicates there is significantly greater susceptibility to yellow spot than to *Pachymetra* root rot or orange rust in the clones in this trial. The

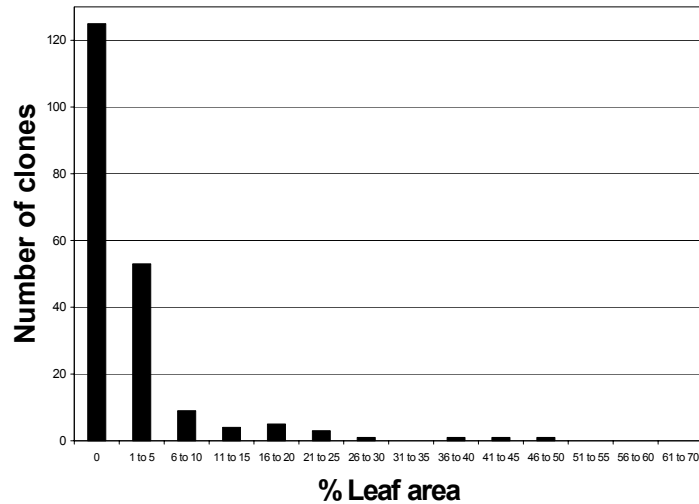
resistance of parent canes to yellow spot also appears low compared to orange rust; compare Figures 2 and 3 for all parent clones.



**Figure 1. Levels of yellow spot resistance (R = resistant, I = intermediate, S = susceptible) of parent clones sourced from each district of Queensland (N = northern; H = Herbert; A = Burdekin; C = central; S = southern).**



**Figure 2. Range of resistance of parent clones to yellow spot, as indicated by leaf area diseased. Very few parents in this assessment in 2000 showed low disease incidence.**



**Figure 3. Range of resistance of parent clones to orange rust, as indicated by leaf area diseased. In contrast to yellow spot, there are a number of parent canes with no disease.**

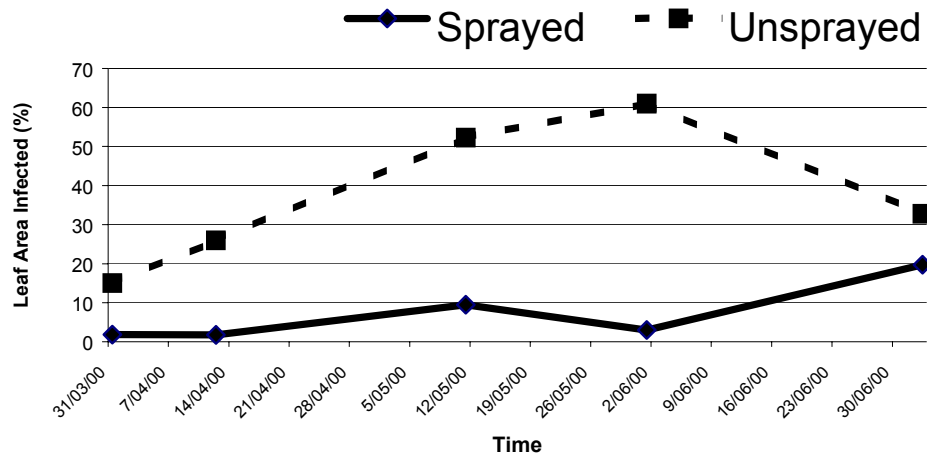
**Table 1. Yield Loss Resistance Index (YLRI<sub>5</sub> - level of resistance needed in clones to restrict yield losses to 5%) and Resistance Index (RI) for each disease calculated for the clones in the 1999-planted FAT series in northern Queensland.**

Disease	YLRI <sub>5</sub>			Resistance index (RI)
	Sugar content (CCS)	Cane yield (t/ha)	Sugar yield (t/ha)	
Yellow spot	Not applicable	2.2	3.1	6.0
Orange rust	>9	7.8	5.0	2.2
Pachymetra	Not applicable	3.5	5.7	3.7

## 4.2 Yield loss studies

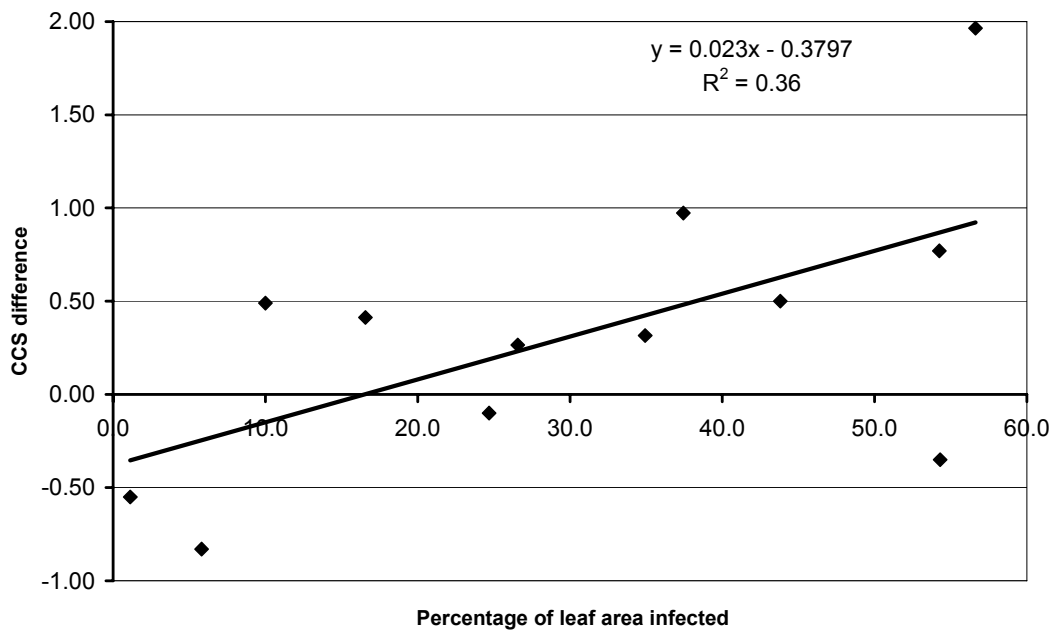
### 4.2.1 Fungicide trials

Benomyl provided good control of yellow spot in each experiment. There were high levels of disease in the small-plot experiment, but low levels in the large-plot experiment where rainfall was well below average during the wet season. In the small-plot experiment, monitoring of yellow spot during the wet season indicated the level of control achieved with benomyl; Figure 4 illustrates this in the susceptible cultivar Q133.



**Figure 4. Leaf areas diseased in sprayed and unsprayed plots of the susceptible cultivar Q133.**

CCS analysis of the small-plot fungicide trials suggested a strong relationship between CCS and yellow spot susceptibility (Figure 5). Losses in CCS of about 2 units appeared to result from yellow spot incidence in susceptible clones. Losses in resistant canes were generally insignificant (or even negative).



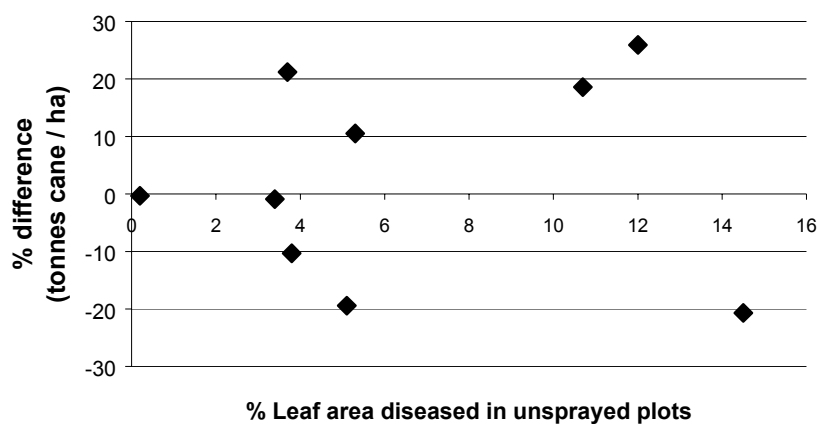
**Figure 5. Effect of clonal resistance on differences in CCS between sprayed (healthy) and unsprayed (yellow-spot affected) small plots. Variation in the percent leaf area diseased reflects variation in the resistance of the clones in the experiment.**

This difference was further explored in the susceptible cultivar Q133 with the monitoring of changes in CCS during the growth and harvest season as yellow spot disappeared (Table 2).

**Table 2. Variation in CCS in sprayed and unsprayed plots of the susceptible cultivar Q133 during pre- to mid-season sampling in the small-plot trial.**

Parameter	Date		
	19 May	11 July	30 August
CCS - Sprayed	6.59	12.76	14.02
CCS - Unsprayed	5.26	11.89	13.55
CCS difference	1.33	0.87	0.47
% difference	25.3	7.3	3.4

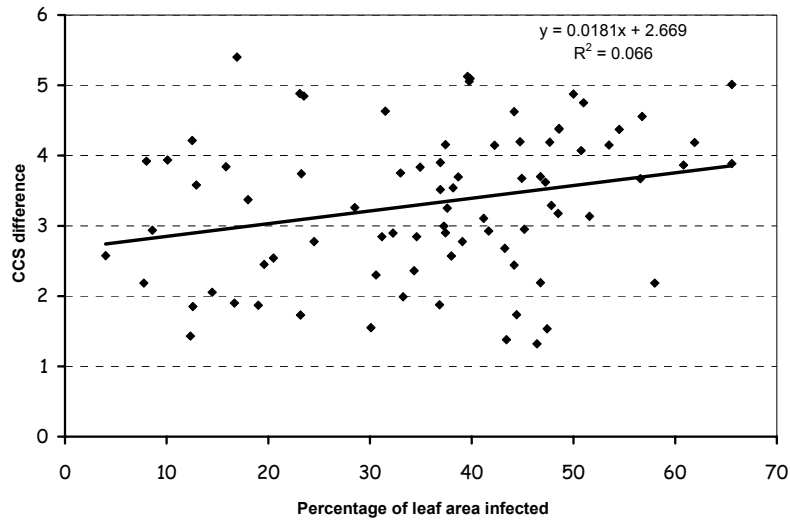
The large-plot experiment was conducted in the relatively dry 2001-2002 season; this resulted in no significant relationship between resistance to yellow spot and yield (Figure 6). This was not surprising given the low levels of disease observed in susceptible clones.



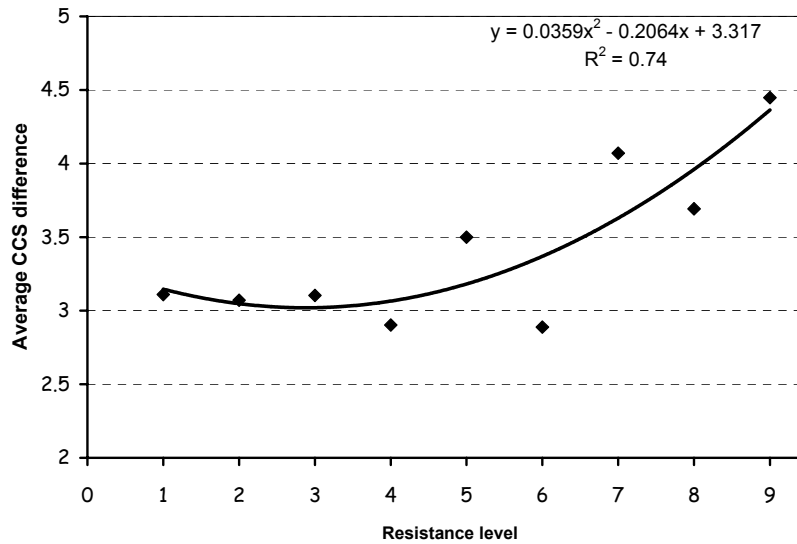
**Figure 6. Relationship between disease level (created through the incorporation of clones of differing resistance) and yield increases accompanying fungicide control of the disease in paired plots. There was no significant relationship ( $R^2=0.004$ ).**

#### 4.2.2 Breeding trials

Considerable data were collected on the relationship between yellow spot resistance and yield (CCS, cane and sugar). Early versus mid-season comparison of the CCS in clones varying in resistance to yellow spot at the South Johnstone site (2000 season) suggested a significant influence of the disease on CCS, but this was apparent only when the mean data for each resistance rating were calculated (Figures 7 and 8).



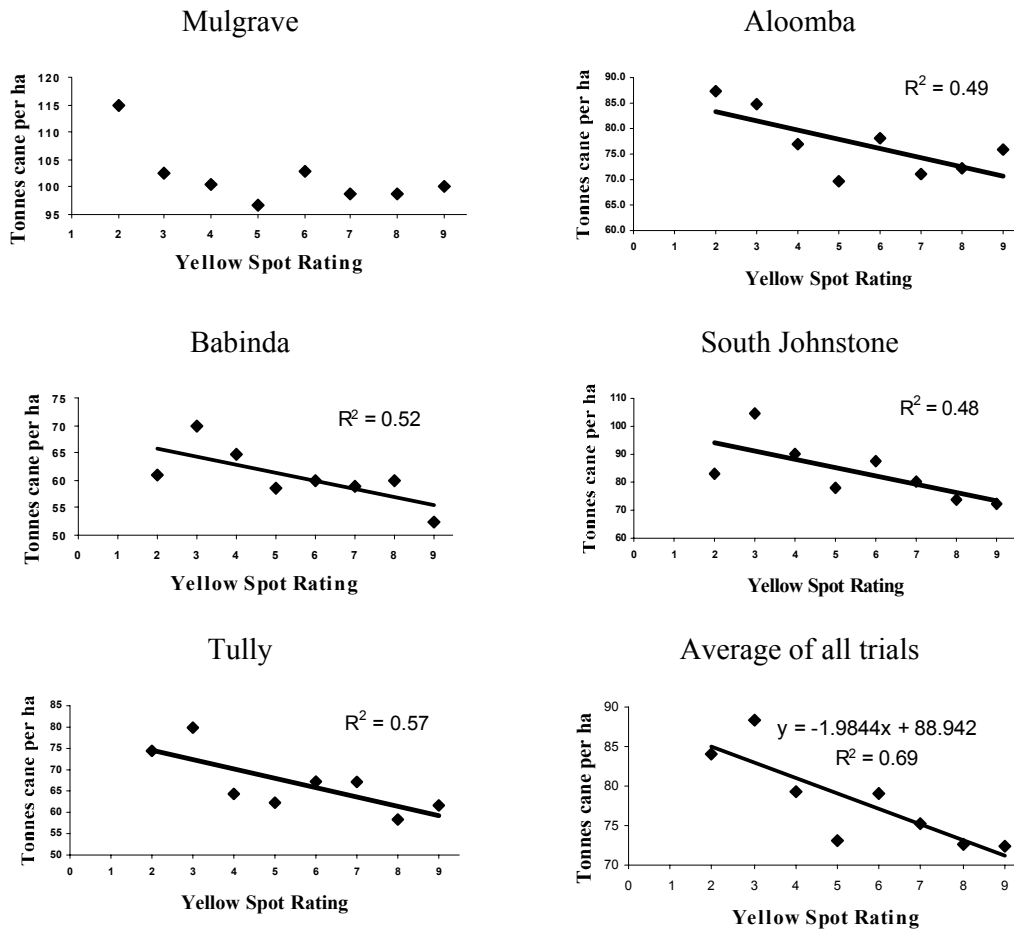
**Figure 7. Differences in CCS early to mid-season in individual clones in the South Johnstone FAT in 2000.**



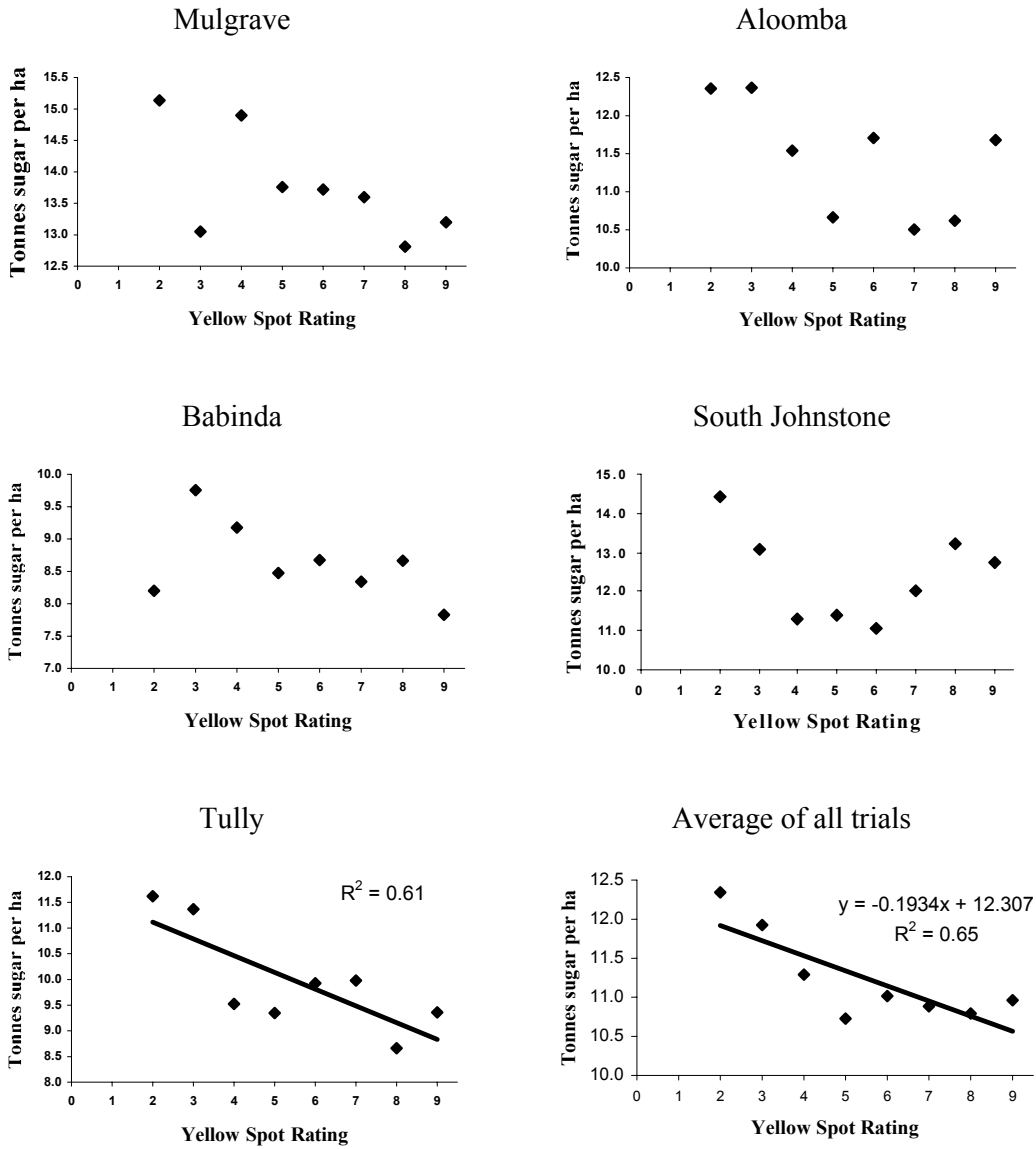
**Figure 8. Change in CCS between early and mid-season assessment as affected by varietal resistance (average of clones with the same resistance rating).**

In susceptible clones, the improvement in CCS between early and mid-season was about 1.5 units greater than in resistant clones. A greater difference might be expected in susceptible clones, since recovery from the disease is known to occur; *ad hoc* observations suggest depressed CCS is temporary in commercial crops. Further analysis of the data is needed to determine what component of CCS was affected by yellow-spot resistance.

An analysis of the harvest data for all FATs on the wet tropical coast suggested a strong effect of yellow spot on cane yield and sugar yield (Figures 9-10). Surprisingly, when mid-season CCS in clones was compared to yellow-spot resistance (rather than the change in CCS early to mid-season), higher CCS was associated with yellow spot susceptibility (Figure 11).

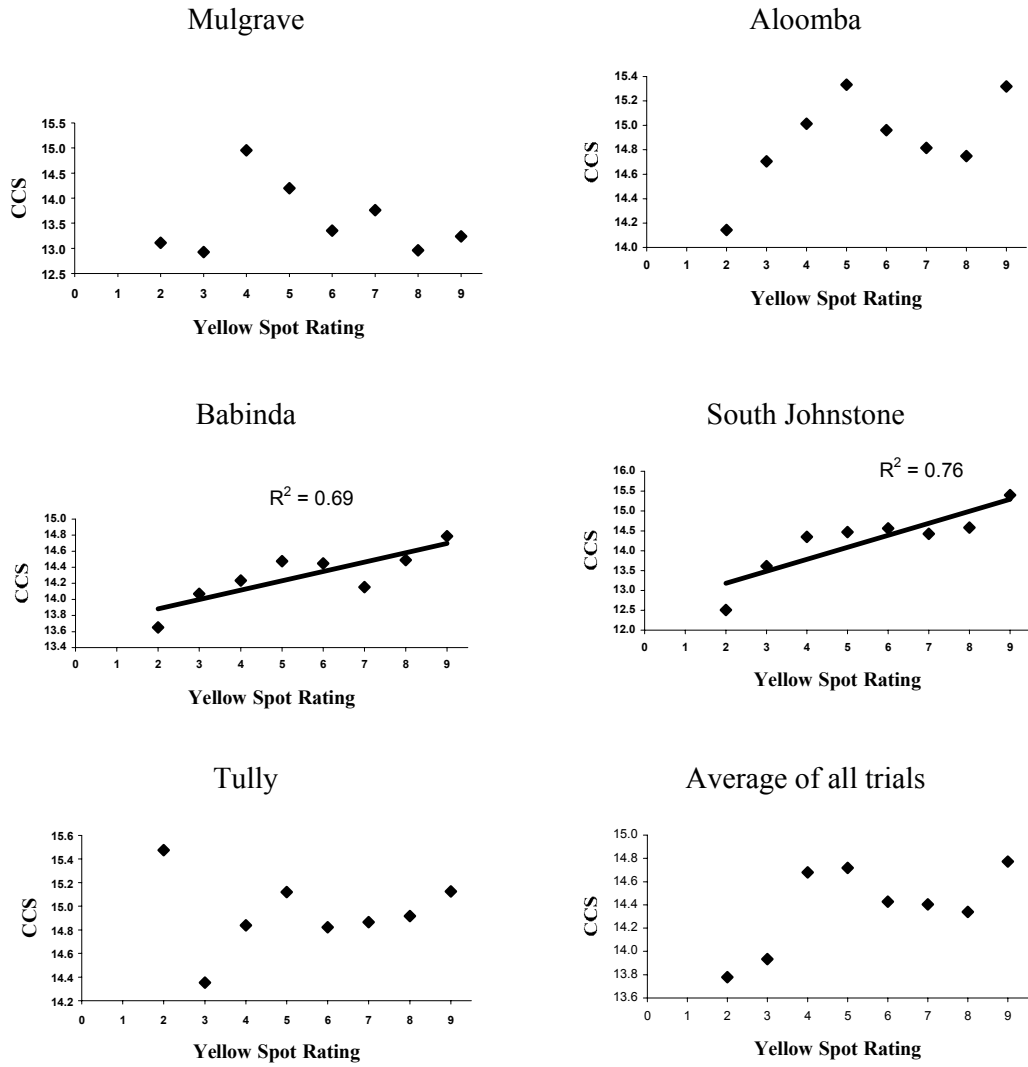


**Figure 9. Effect of yellow spot on cane yield in FAT breeding trials at five locations in northern Queensland (only significant relationships are shown).**



**Figure 10. Effect of yellow spot on sugar yield in FAT breeding trials at five locations in northern Queensland (only significant relationships are shown).**





**Figure 11. Effect of yellow spot on CCS in FAT breeding trials at five locations in northern Queensland (only significant relationships are shown).**

### 4.3 Influence of environment

Results from the temperature and relative humidity studies on spore germination provided some of the first data relating to the effects of these parameters on the development of yellow spot.

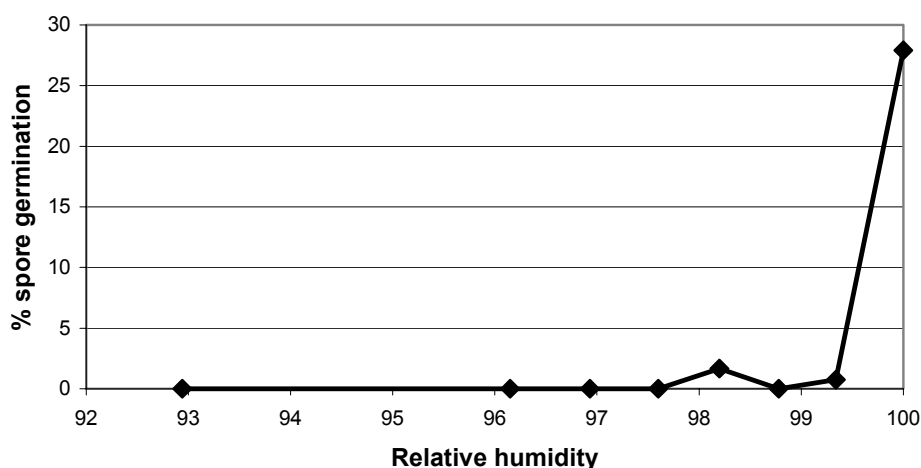
#### 4.3.1 Laboratory studies

Germination of spores of *M. koepkei* is favoured by warm temperatures; this is illustrated in a summary of the conditions needed for spore germination in *M. koepkei* compared to the two Australian rust pathogens *Puccinia melanocephala* (brown rust) and *P. kuehnii* (orange rust) – data obtained for these pathogens in other studies (Table 3).

**Table 3. Optimum temperatures for spore germination of three fungal pathogens of sugarcane.**

Disease	Pathogen	Optimum temperatures (°C)
Brown rust	<i>Puccinia melanocephala</i>	11-27
Orange rust	<i>Puccinia kuehnii</i>	17-23
Yellow spot	<i>Mycovellosiella koepkei</i>	20-30

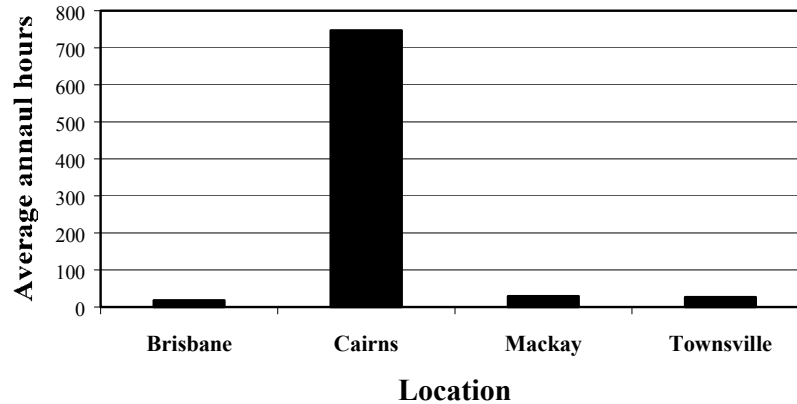
*M. koepkei* requires conditions of very high humidity for spore germination (>99% RH) (Figure 12). Free water on leaf surfaces is probably needed in most instances for spore germination.



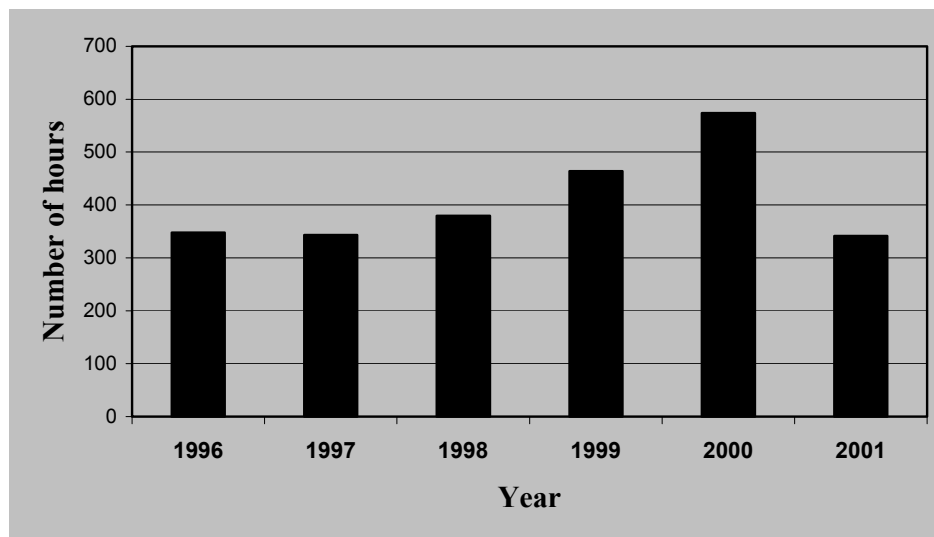
**Figure 12. Effect of relative humidity on spore germination in *M. koepkei*; relative humidities varied from 93-100% and conidia were incubated at 21°C. Germination in free water was 54.6%.**

### 4.3.2 Weather data analyses

Analysis of the weather data for Cairns, Townsville, Mackay and Brisbane for conditions suitable for germination of yellow spot strongly suggested that Cairns is the most suitable (Figure 13). Analysis for Cairns comparing years during 1996-2001 shows considerable difference between years in suitability (Figure 14).

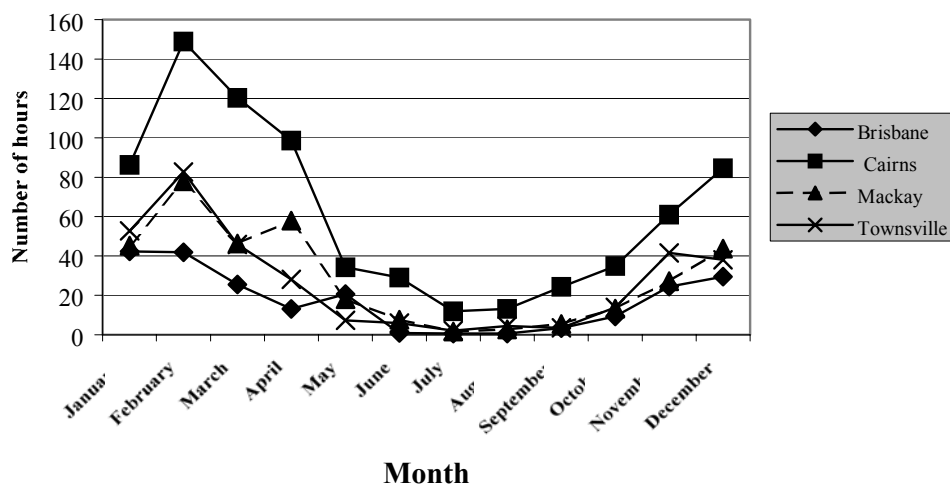


**Figure 13. Average annual number of hours conducive to germination of spores of *M. koepkei* for Cairns, Townsville, Mackay and Brisbane using data from the Bureau of Meteorology for 1996-2001.**



**Figure 14. Annual number of hours conducive to germination of spores of *M. koepkei* in the Cairns area in each year of 1996-2001.**

Comparison of monthly suitability for germination of spores of the yellow spot pathogen at each of the four sites (Figure 15) indicates that the hot and humid months favour germination.



**Figure 15. Average number of hours in each month with suitable conditions for germination of spores of *M. koepkei* at Cairns, Townsville, Mackay and Brisbane (1996-2001 data).**

Overall, these data suggest that Cairns is the area most favourable to the disease, that the 2000 season was the most suitable for *M. koepkei* spore germination, and that the wet season is when conditions are suited to spore germination. These data are supported by general industry disease observations.

## 5.0 DISCUSSION

This study provides a significant amount of new information on the effects of yellow spot on sugarcane yield in Queensland. Breeding trial analyses clearly indicate the disease may significantly reduce cane and sugar yields by up to 20% in years of above average rainfall. In fact in the 2000 crop, yellow spot was of greater significance than *Pachymetra* root rot and orange rust (refer to Table 1). Fungicide research confirmed the significance of the disease and showed that yellow spot may reduce the CCS of susceptible canes early in the harvest season, but that this effect disappears as winter (the dry season) approaches. These CCS results concur with those reported by Egan (1973) with similar reported losses of around 2 units early in the season.

The reason for the positive correlation between yellow spot susceptibility and mid-season CCS in breeding trial analyses is obscure. Yellow spot reduces CCS early in the harvest season when the crop canopy is suffering maximum loss of photosynthetic area (Ricaud *et al.* 1980). The breeding trials in our project were harvested mid-season. The apparent positive correlation between CCS and susceptibility at some sites was therefore surprising and warrants further investigation. Research in Mauritius in the mid-1970s established low CCS as the primary effect of the disease early in the harvest season and reduced cane yield as the main effect later in the harvest season (Ricaud *et al.* 1980). We saw reductions in cane yield, particularly at Babinda, South Johnstone and Tully. These three centres are where maximum disease is usually seen. Yellow spot is favoured by high rainfall and the highest rainfall in Australia occurs each year in the region bounded by these towns (>4,100 mm).

Two new indices relating to either the resistance of a breeding population (RI) or yield loss (YLRI<sub>5</sub>) were generated and these enabled an assessment of the effect of yellow spot on yield and the level of resistance needed to minimise losses. A low RI value (that is, a low level of susceptibility in that group of clones) with a high YLRI<sub>5</sub> (implying even highly susceptible clones don't suffer large losses), would suggest there is a high level of resistance in the germplasm with the disease having only a small effect on yield. On the other hand, a high RI value and a low YLRI<sub>5</sub> suggest there is a low level of resistance but the disease has the potential to greatly reduce yields. Analyses using yellow spot data clearly suggested the latter was the case in the 2000 season – namely that there was a low level of resistance to yellow spot in the germplasm and that yield losses were significant. When the yellow spot data were compared to similarly calculated figures for *Pachymetra* root rot and orange rust, yield losses were lower with both the latter diseases and there were higher levels of resistance in clones in the breeding program. It is clear that the current breeding strategies for yellow spot appear to be inappropriate, as there is insufficient resistance in the breeding population to minimise losses. The generation of these data, coupled with the first quantitative assessment of the resistance of parent canes for many years, is enabling improved strategies in the breeding program to be deployed. The introduction of higher levels of resistance in parents will have a two-fold effect, of reducing the level of yellow spot in clones in the breeding program (and subsequently in commercial crops), and increasing yield and particularly early season CCS in newly-bred varieties.

An issue of significance here is the uniqueness of the weather conditions during the course of this study. Research into the conditions needed for spore germination with *M. koepkei*, coupled with the analysis of weather data for the 1996-2001 period, suggest that 2000 was very well suited to the pathogen while other years were slightly less favourable to the disease. This was illustrated in the results obtained in the second fungicide trial, which was subject to a dry 'wet season'. In this experiment, there was no correlation between disease levels (resistance) and yield with relatively low disease levels experienced in the trial period. Further YLRI and RI data will be needed over an extended period to determine the average influence of yellow spot on yields on the wet tropical coast and the optimum breeding strategy can only be formulated once these data are to hand. It was thus identified during this study that objectives two and three from the project ('assessing the efficiency of selection for yellow spot resistance operating in the plant improvement program', and 'initiate strategies for improving CCS in the plant improvement program') can only be fully and efficiently researched/implemented once a number of years data are to hand. As selection efficiency and yield loss are dependant on disease severity, annual variation in weather conditions will affect both aspects.

What has occurred, even at this point, is the annual assessment of the yellow spot resistance of elite parent material and the use of these data for parent selection in the crossing program. It is hoped to obtain further resources for examining the mid-parent rating of the actual crosses made each season. This will provide a better idea of the resistance of seedlings entering the selection program. By comparing the average resistance of these clones (the RI of this population) with the RI of clones in the latter stages of selection, it will be possible to see whether there has been a shift in the resistance of populations during the selection process. This will indicate the efficiency of selection for yellow spot in the routine breeding selection process. Armed with further weather data, and information on temperature and humidity requirements for yellow spot,

differences in selection efficiency between years will be able to be related to weather conditions. With some years information to hand, the likely 'average' and extreme effects of the disease will be able to be quantified and the importance of the disease well established.

Yield data will be accessible on an on-going basis using FAT data, as long as the resistance of clones can be assessed each year as undertaken at the South Johnstone FAT site. If continuing studies can be undertaken, and further research conducted into the influence of weather on other aspects of disease development, the analysis of long-term weather data may then be useful in predicting yield losses not only on the wet tropical coast, but also anywhere where weather data is available and sugarcane is being grown.

Clear directions for further research, development and application were gained during the course of the work and are detailed below.

## 6.0 OUTPUTS

- CCS losses resulting from yellow spot were found to be as high as 2 units early in the harvest season.
- The effects of yellow spot on CCS were shown to decrease to near zero by mid-season harvest.
- Yellow spot was shown to significantly reduce yield (both tonnes cane/ha and tonnes sugar/ha), in breeding trial analyses on the wet tropical coast. Losses reached 20% (tonnes cane/ha) in the wet 2000 season.
- The disease was as, or more, significant than *Pachymetra* root rot and orange rust in reducing the yield of sugarcane on the wet tropical coast in the 2000-2001 period.
- The resistance of parent canes originating in each region of Queensland was assessed; there was little difference between point of origin and a generally low level of resistance prevailed in these varieties.
- Low levels of resistance were also found in clones in the latter stages of the plant-breeding program in the northern program.
- Resistance ratings on parents were provided to plant breeders to incorporate into the parent crossing selection computer software.
- Methods for assessing yield losses incorporating plant breeding trials were shown to be successful and these trials provide a low cost source of on-going yield loss information.
- The effect of temperature and humidity on spore germination in *Mycovellosiella koepkei* revealed that free water (or 100% relative humidity) and relatively high temperatures (20-30°C) are needed.
- The analysis of weather data for four major cities (Cairns, Townsville, Mackay and Brisbane) suggested Cairns is the most favourable. This matches the observed distribution of the disease. Further analysis of weather data for the region affected by the disease will enable a linkage between these data and yield losses. In turn, weather data may provide a way to assess the long-term effects of the disease on sugarcane yields.
- Several research papers have been written and the information extended to industry.

## 7.0 EXPECTED OUTCOMES

- More attention will be paid to the disease by industry (in choice of commercial varieties) since the effects of the disease have been quantified.
- Attention will be paid to yellow spot resistance in the choice of parents in the crossing program. This will increase the resistance of clones coming through the breeding program, reduce losses in tonnes cane/ha and lead to an increase in early season CCS in commercial crops.
- Application of resistance ratings to promising clones in the final stage of selection will become routine in northern Queensland. This will enable yellow spot resistance to be taken into account in the selection of varieties for commercial production.
- The project has enabled yield loss method development that will facilitate the ongoing assessment of losses and the quantification of the 'average' and 'extreme' losses able to be caused by this disease.

## 8.0 FUTURE RESEARCH NEEDS

- Continue to assess yellow spot-associated yield losses in breeding trials.
- Further research the weather requirements for yellow spot.
- Obtain weather data for subdistricts within the regions affected by yellow spot over a long period (10 years or more) to allow modelling and prediction of the long-term effects of the disease on sugarcane yield. The installation of weather stations at all FAT sites would enable a link between weather and yield loss data.
- Monitor changes in the resistance (*RI*) of populations of clones as they progress through the breeding selection program. This will show whether selection for resistance is occurring in early-stage breeding trials, whether adequate resistance is being incorporated in crosses and whether early screening of seedlings is needed to shift populations toward resistance.

## 9.0 RECOMMENDATIONS

Further research into various aspects of the disease is needed (as detailed above). Studies reported here have provided a foundation of information that now needs to be further expanded. The greatest needs are:

- Long-term yield loss information.
- A better understanding of the weather conditions required for the disease coupled with long-term weather data from a number of sites in affected districts.
- Further interaction between breeders and pathologists to implement the best long-term strategy for breeding for yellow spot resistance.
- Funding to accomplish this research.

## 10.0 PUBLICATIONS ARISING FROM THE PROJECT

- Magarey, R.C., Bull, J.I., Neilsen, W. and Magnanini, A. (2002). The use of breeding trials to estimate disease-induced yield losses and to refine selection strategies. *Proceedings of the Australian Society of Sugarcane Technologists* 24, 113-122. **(Appendix 1).**
- Magarey, R.C., Bull, J.I. and Neilsen, W.A. (2003). Yield losses caused by several endemic diseases in Queensland. *Proceedings of the Australian Society of Sugarcane Technologists* 25 **(Appendix 2).**
- Magarey, R.C., Bull, J.I., Neilsen, W.A., Camilleri, J.R. and Magnanini, A.J. Relating cultivar resistance to sugarcane yield using breeding selection trial analyses - orange rust and yellow spot. *Australian Journal of Experimental Agriculture* (under review) **(Appendix 3).**
- Magarey, R.C., Neilsen, W.A., Staier, T., Bull, J.I. and Magnanini, A.J. Preliminary studies into pathogen environmental requirements for predicting leaf disease occurrence in Queensland. Prepared for submission to *Proceedings of the Australian Society of Sugarcane Technologists* 26 **(Appendix 4).**

## 11.0 ACKNOWLEDGMENTS

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# APPENDICES